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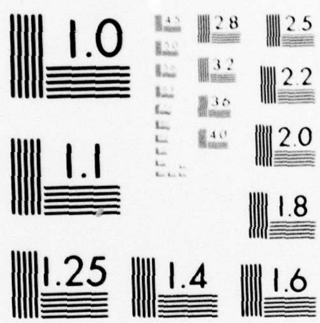

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FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

SUPERCRITICAL PROFILE

by

V. Molozhavtsev

FOREIGN TECHNOLOGY DIVISION

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А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yë or ë.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

0270,gw

SUPERCRITICAL PROFILE

V. Molozhavtsev, Candidate of Technical Sciences

On modern subsonic aircraft a wing is used, the profile of which has a significant relative thickness and a positive curvature. Beginning with a certain Mach number of flight which is called the critical Mach number ($M_{кр}$), zones of local supersonic velocities are formed on such a wing. This leads to the appearance of local shock waves and as a result, to the occurrence of irreversible losses of mechanical energy, which is converted into thermal energy. Wave drag arises and leads to an increase of the total drag.

With an increase in the flight speed the zone of the shock stall on the upper surface is displaced to the tail portion of the wing and the shock wave becomes stronger. In addition a shock wave appears on the lower surface of the wing. With a strongly developed shock stall

behind the shock wave it is possible that the boundary layer will break away from under the shock wave. An unfavorable picture of pressure distribution is obtained under conditions of shock stall with an increase of the Mach numbers (Fig. 1). The peak of rarefaction on the upper surface decreases and in the tail portion a significant negative lift force arises. As a result there is a sharp decrease in the permissible lift coefficients $C_{y_{доп}}$, the head resistance increases and the center of pressure is displaced forward leading to large changes of the longitudinal moment. In this case the position of the upper and lower shock waves is not constant, which along with the breakaway of flow from under the shock wave is accompanied by shaking in flight.

With positive values of the lift force of the wing, with an increase in the angle of attack, value $M_{кр}$ decreases, i.e., all phenomena accompanying shock stall develop even at lesser flight speeds.

In the final analysis, with an increase of Mach numbers of flight the permissible lift coefficients $C_{y_{доп}}$ decrease with respect to conditions of stability and controllability, as do the values of maximum aerodynamic quality $K_{макс}$. Beginning with a certain Mach number the latter begin to decrease very sharply (Fig. 3). Such an unfavorable course of the characteristics $C_{y_{доп}}$ and $K_{макс}$ with large

Mach numbers of subsonic flight leads to a deterioration of maneuverability and to a reduction of the range of the aircraft. Therefore the problem of raising the critical Mach numbers of wing profiles is quite urgent. At one time attempts were made to find so-called "Mach-stable" shapes of profiles which include symmetrical profiles with distribution of the maximum thickness more to the rear. They did not produce the desired effect.

On supersonic aircraft they used a wing with a very thin and almost symmetrical profile. It contributed to a delay of the shock stall and to an increase of $M_{кр}$. While for subsonic aircraft the greatest range of flight corresponded to M = 0.7-0.75, for supersonic aircraft it was M = 0.85-0.9. But the carrying properties of a wing with constant sweep turned out to be low. In addition in connection with the small length of the wing the maximum aerodynamic quality became 25-35 $^0/_0$ less than for subsonic aircraft and reserves of lift force during.maneuvering remained insufficient. Even in supersonic aircraft in the subsonic area of large Mach numbers the same unfavorable phenomena are observed which are brought about by shock stall although it takes place less intensively.

How can such phenomena be reduced in the near-sonic range of Mach numbers? In searching for a solution to this problem the concept of supercritical profile arose. In contrast to a conventional profile

it has an almost plane (flattened) upper surface and a considerably bent-in lower surface in the tail portion.

On a wing of such profile (Fig. 4) pressure on the lower surface is distributed nonuniformly and on the upper surface, practically uniformly. In connection with this the appearance of shock waves on the upper surface is limited and $C_{y_{\text{доп}}}$ drops less intensively with an increase in the Mach number.

A supercritical shape of the profile does not eliminate shock waves but shifts them to the rear edge, thereby decreasing wave drag and the phenomenon of breakaway at near-sonic Mach numbers. Shock stall develops intensively at M = 0.95-0.98 and not at M = 0.8-0.85 as in the best modern profiles.

As a result, the value $\frac{M \cdot K_{\text{макс}}}{C_e}$ which determines the range of flight increases up to Mach numbers of M = 0.95. Consequently the economy of near-sonic flight must increase (Fig. 5).

No less important is the effect of raising the permissible lift coefficient $C_{y_{\text{доп}}}$ (Fig. 6) which is quite favorably manifested in flight safety of heavy aircraft in turbulent air and also in the maneuverability of fighter aircraft.

Thus the idea of a supercritical profile is quite promising. At least this is borne out by reports on research conducted in wind tunnels. However, the wind-tunnel characteristics of a profile change significantly in the total aerodynamic make-up of a full-size airplane. The operation of a wing of supercritical profile is affected by its variable sweep, the arrangement of the engines and suspensions, mechanization, and shape in a plane. Therefore during the development of each specific aircraft, in connection with the development of the wing, considerable research on complete models in wind tunnels is unavoidable.

The introduction of a wing with a supercritical profle, judging from reports in the press, is preceded by thorough research on experimental aircraft. This research, in the first place, must provide information on the applicability of the new design not only for relatively thick, but also for thin profiles; second, it must prepare recommendations for the aerodynamic make-up of wings with a supercritical profile for aircraft of various designations; and third, it must evaluate the effect of production deviations and in-flight deformations on the characteristics of the profile.

As is known, in the USA, NASA began to study the supercritical profile around 1966-1967. It was announced that research in wind tunnels confirmed the possibility of increasing the critical Mach

number by 18 %. According to the preliminary evaluation the use of a supercritical profile should increase the range of a passenger aircraft of the type Boeing-707 by 15 % when cruising with a Mach number of M = 0.9 instead of 0.8, without an increase in the thrust of the engines.

Then modifications were made in the trainer T-2C and in the fighter-bomber F-8 "Crusader" with a wing with a supercritical profile. The wings of these airplanes have a considerable relative thickness. It is reported that tests of the T-2C and the F-8 confirmed the results of research in wind tunnels.

In 1971 a contract was let for modification of the supersonic fighter-bomber F-111A with a wing with a supercritical profile. By placing the wing in a position with minimum sweep it is proposed to improve the economy of flight and maneuverability without detracting from controllability.

The enumerated experimental works are united by a single intent: to reveal the possibilities of a supercritical profile. Especially great hopes are placed on the experiment with the F-111A. Results of the experiment will be used in the construction of new, maneuverable, tactical aircraft and possibly in the construction of the strategic bomber B-1.

From reports in the press it follows that if the full-scale experiments in flight are completed with positive results then aerodynamics will acquire another technical possibility for increasing the efficiency of aircraft in the near-sonic range of flight which up until now has been the most unfavorable.

Figures 1-6. KEY: 1) Negative lift force; 2) Zone of separated vortex flow; 3) Conventional flow; 4) Shock wave; 5) Conventional; 6) Supercritical; 7) Supercritical profile.

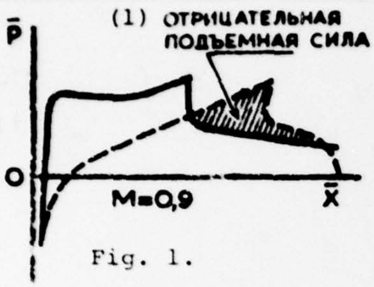


Fig. 1.

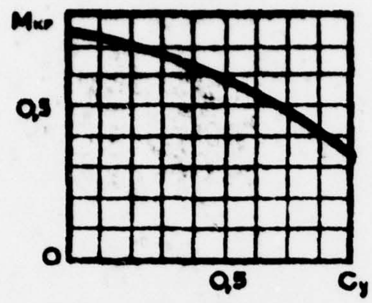


Fig. 2.

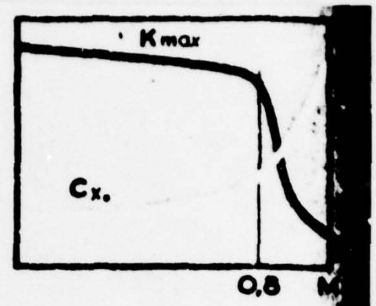
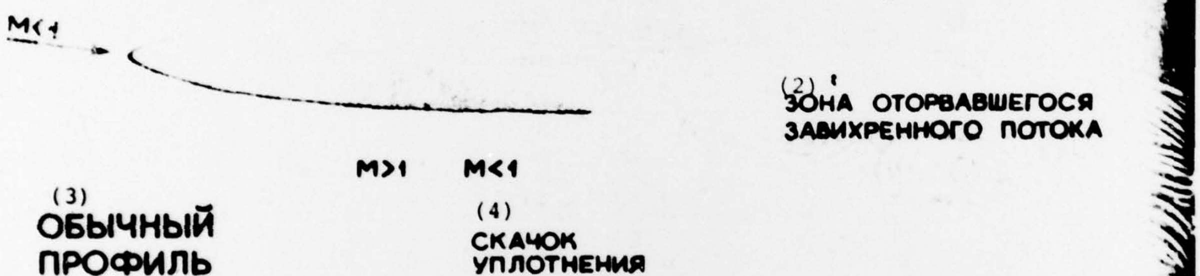


Fig. 3.



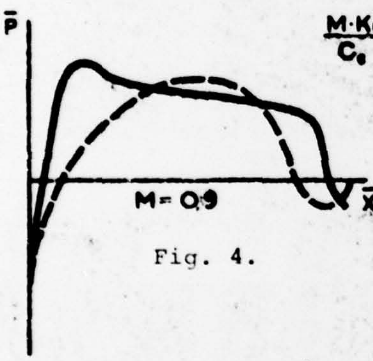


Fig. 4.

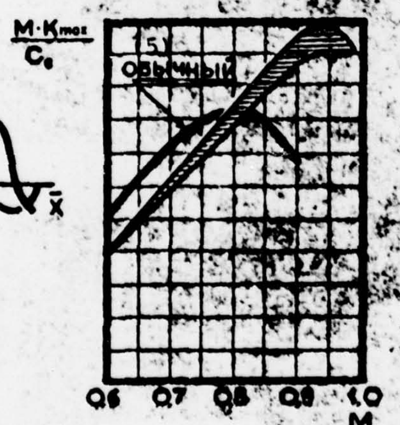


Fig. 5.

Fig. 6.

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